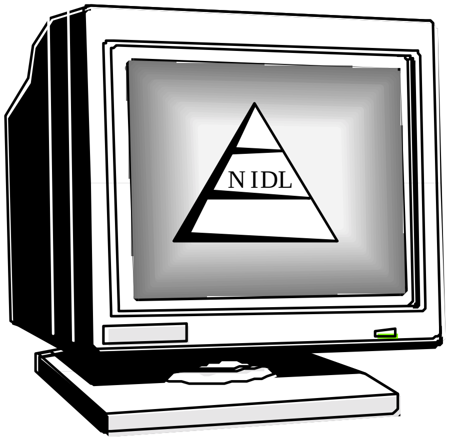

The Precision Imaging Corporation 21si CRT monitor manufactured by Siemens (Siemens model number 21103L Stereo) is an excellent 1600 x 1200 pixel, 21 inch monochrome gray scale monitor. The monitor easily passes all the IEC monochrome monitor specifications for both monoscopic and stereo viewing. This COTS monitor is an excellent display for NIMA Imagery Exploitation Workstations. Accordingly, NIDL certifies the PIC21si and the Siemens look-alike monochrome monitor as being suitable for IEC workstations requiring a monochrome monitor. The monitor passes all stereo specifications with a StereoGraphics Z-screen and its associated passive glasses, with a Nuvision panel and its associated passive glasses, and with StereoGraphics active glasses. NIDL rates this monitor as an “A” for the Image Analyst and Cartographer applications

Evaluation of the Precision Imaging Corporation 21si 4 x 3 Aspect Ratio, 21-Inch Diagonal Monochrome Monitor

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Abstract

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Number of Pages
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CONTENTS

NIDL IEC Monitor Certification Report

The Precision Imaging Corporation 21si Monochrome CRT Monitor

FINAL GRADE: A

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way

The Precision Imaging Corporation 21si CRT monitor manufactured by Siemens (Siemens model number 21103L Stereo) is an excellent 1600 x 1200 pixel, 21 inch monochrome gray scale monitor. The monitor easily passes all the IEC monochrome monitor specifications for both monoscopic and stereo viewing. This COTS monitor is an excellent display for NIMA Imagery Exploitation Workstations. Accordingly, NIDL certifies the PIC21si and the Siemens look-alike monochrome monitor as being suitable for IEC workstations requiring a monochrome monitor. The monitor passes all stereo specifications with a StereoGraphics Z-screen and its associated passive glasses, with a Nuvision panel and its associated passive glasses, and with StereoGraphics active glasses. NIDL rates this monitor as an "A" for the Image Analyst and Cartographer applications.

The PIC21si/Siemens21103SL monitor has a very wide possible dynamic range. It easily meets the 300:1 dynamic range in stereo, achieving 35.6 fL for Lmax and 0.1 fL for Lmin for a dynamic range of 356:1. The maximum luminance, Lmax, is readily adjustable from the front panel control to achieve values from 35 fL, or lower, to 170 fL as might be used in stereoscopic mode to achieve 35 fL through the ZScreen and passive glasses. As Lmax is adjusted, Lmin remains constant at 0.1 fL, which is useful to the analyst when changing from mono to stereo mode.

Resolution of the monitor is of interest for the analyst. At the 1600 x 1200 pixel addressability, a single 1-pixel wide line measures 10.6 mils (full width at half maximum) at 17 fL. It is somewhat luminance- and focus-dependent. Carefully adjusting the focus reduces the spot size to 10.1 mils from its value of 10.6 mils. Increasing the luminance to 35 fL results in a 10.9 mil line width, to 85 fL in 11.3 mils, and to 170 fL in 11.9 mil line width. According to the manufacturer, the difference between the PIC and the Siemens monitors is that Siemens optimizes the performance at the factory for 170 fL operation (from here forward, this will be changed at the factory to a 35 fL optimization point), while PIC readjusts after receipt to 35 fL for its NIMA customers.

The Resolution-Addressability-Ratio for the PIC/Siemens monitor combines the electron beam and pixel sizes; RAR=beam/pixel. RAR is a dimensionless measure of the fill factor between pixels. If RAR <1, the display will have noticeable structure in solid fields because the spot size does not adequately fill the interpixel space when all pixels are on. If RAR>1.5, then the modulation transfer function, or the contrast modulation corresponding to a particular spatial frequency such as 1 pixel on/1 pixel off, is degraded. For the PIC21si the RAR is close to 1, which produces an excellent image without showing horizontal scan lines. The contrast modulation for 1 pixel on/1 pixel off exceeds the IEC requirement by 20% to 50% at 170 fL and by even more at a luminance setting of 35 fL. Further, the resolution is excellent over the whole screen as demonstrated by the clear resolution of a 1 pixel on/1 pixel off EM pattern at all locations on the screen.

The PIC monitor was chosen for use at JICPAC based on a critical selection of important features and performance. Any failed monitors have been replaced by the manufacturer.

NIDL has evaluated alternative COTS monochrome monitors from Orwin and will shortly issue reports on their performance. The 1600 x 1200 pixel, landscape Orwin DEX2101L monitor has performance very similar to the PIC21si/Siemens monitor. The Orwin 1988 landscape monitor with the NIDL-designed electron gun in native 1408 x 1408 pixel format is like the Orwin 1974D vertically scanning replacement for the specially-manufactured original IDEX monitor. Its contrast modulation at 1 pixel on/1 pixel off exceeds either the PIC21si or the Orwin DEX2101L at the 120-170 fL luminance levels, while other performance values are similar to the PIC or DEX2101L. Reducing the luminance of the PIC to 35 fL, brings the monoscopic contrast modulation to nearly that of the Orwin 1988. If the CRT in the 1988 were changed to a different supplier, the 1988 would have to be evaluated again for performance. Thus, all three monochrome monitors pass the IEC minimum specifications. The choice may be made on price for the IEC workstation.

Siemens has manufactured the monochrome monitor for radiology applications for a number of years. NIDL evaluated a predecessor model, SIMOMED 90H in August 1994. The publication number is 313894-027.

The Siemens web site is at http://www.ad.siemens.de/monitors/html_76/ftp/smm21103ls_en.pdf.
The PIC web site is at http://www.picmon.com/.
The Clinton/Orwin website is http://www.cec-displays.com/index2.htm.
The StereoGraphics web site is at http://www.stereographics.com/.

Evaluation Datasheet

PIC21si monochrome monitor at 174 fL luminance

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	pass
Dynamic Range	25.4 dB	30.8 dB	pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.1 fL	pass
Luminance (Lmax)	35 fL ± 4%	174 fL	pass
Uniformity (Lmax)	28% max.	15.5%	pass
Halation	3.5% max.	1.4%	pass
Color Temp	Not specified	12333 K	N/A
Reflectance	Not specified	7.4%	N/A
Bit Depth	8-bit± 5 counts	8-bit	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 Δ u'v'	0.0046 delta u'v'	pass
Pixel aspect ratio	Square H = V± 6%	Set to square	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.4 ins.	pass
Cm, Zone A, 7.6 inch dia.	35% min.	45%	pass
Cm, Zone A, 40% area	35% min.	42%	pass
Cm, Zone B	20% min.	33%	pass
Pixel density	72 ppi min.	104 ppi	pass
Straightness	0.5% max ± 0.05 mm	0.55%	pass
Linearity	1.0% max ± 0.05 mm	0.59%	pass
Jitter	2 ± 2 mils max.	1.79 mils	pass
Swim, Drift	5 ± 2 mils max.	2.14 mils	pass
Warmup time, Lmin to +/- 50%	30 mains. Max ± 0.5 minute	8 mins.	pass
Warmup time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	41 mins.	pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 2048 (I)	pass
Lmin	0.1 fL min. ± 4%	0.1 fL	
Lmax	30 fL min± 4%	35.6 fL	pass
Dynamic range	22.7 dB min	25.4 dB	pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 Δ u'v'	0.008 delta u'v'	pass
Refresh rate	60 Hz per eye, min	60 Hz, per eye	pass
Extinction Ratio	20:1 min	22.1:1 (n)	pass

Note: IEC graphics card limitation for stereo is 1024 x 1024 pixels
(I) denotes interlaced scanning
(n) denotes Nuvision LCD shutter panel and its passive glasses
Note: IEC is deploying with StereoGraphics ZScreen

Evaluation Datasheet

PIC21si monochrome monitor at 35 fL luminance

Mode	**IEC Requirement**	**Measured Performance**	**Compliance**
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	pass
Dynamic Range	25.4 dB	25.5 dB	pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.1 fL	pass
Luminance (Lmax)	35 fL ± 4%	35.6 fL	pass
Uniformity (Lmax)	28% max.	14.6%	pass
Halation	3.5% max.	1.4%	pass
Color Temp	Not specified	12435 K	N / A
Reflectance	Not specified	7.4%	N / A
Bit Depth	8-bit± 5 counts	8-bit	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 Δ u'v'	0.0039 delta u'v'	pass
Pixel aspect ratio	Square H = V± 6%	Set to square	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.4 ins.	pass
Cm, Zone A, 7.6 inch dia.	35% min.	59%	pass
Cm, Zone A, 40% area	35% min.	58%	pass
Cm, Zone B	20% min.	49%	pass
Pixel density	72 ppi min.	104 ppi	pass
Straightness	0.5% max ± 0.05 mm	.44%	pass
Linearity	1.0% max ± 0.05 mm	0.8%	pass
Jitter	2 ± 2 mils max.	1.775 mils	pass
Swim, Drift	5 ± 2 mils max.	1.99 mils	pass
Warmup time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	8 mins.	pass
Warmup time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	41 mins.	pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 2048 (I)	pass
Lmin	0.1 fL min. ± 4%	0.1 fL	
Lmax	30 fL min ± 4%	33.8.fL	pass
Dynamic range	24.77 dB min	25.14 dB	pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 Δ u'v'	0.007 delta u'v'	pass
Refresh rate	60 Hz per eye, min	60 Hz, per eye	pass
Extinction Ratio	20:1 min	30.3:1 (Z)	pass

Note: IEC graphics card limitation for stereo is 1024 x 1024 pixels
(I) denotes interlaced scanning
(n) denotes Nuvision LCD shutter panel and its passive glasses
(Z) denotes StereoGraphics LCD ZScreen and its passive glasses

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the Precision Imaging Corporation 21si, monochrome CRT high-resolution display monitor manufactured by Siemens. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091***,** *Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*

- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*
  Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC), August 25, 1999.

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The Precision Imaging Corporation 21si Monochrome CRT Monitor

Manufacturer's Specifications

The specifications for the PIC21si are contained in the Siemens SMM 21103L Procurement Specification dated March 24, 1998 and on the Siemens web site. The stereo version increases the horizontal scan frequency. The monitor's internal microprocessor controls all electrical and magnetic monitor functions and continuously adjusts drive levels to maintain constant luminance over the life of the CRT. For each format, the dynamic focus ensures optimal sharpness at any point on the screen. Formats are selected and modified through the RS232 serial port on the front of the monitor. The black level is calibrated 20 minutes after power-on and every 12 hours thereafter; no external sensor is needed. A built-in ambient light sensor is used for automatic contrast control.

- **Resolution**: 1600 x 1280 addressability is standard. Monitors in SMM series are Multisync.
- **CRT**: 21 inch flat and square CRT, 27% transmission glass, P45 cadmium free phosphor, 90 degree deflection angle. Dispenser cathode for long life. The multi-layer AR/AS film coating reduces ambient light reflection while the conductive layer helps reduce static charges. Color coordinates during operation are x=0.250 +/-0.02, y=0.305 +/-0.02. Luminance up to 235 fL. Constant Gamma for equal gray scale performance over complete lifetime of CRT.
- **Power requirement**: 90-264 VAC 47-65 Hz; approximately 150W during operation
- **Signal interface**: BNC 75 ohm
- **Scan timing**: Horizontal 70 kHz to 135 kHz; Vertical 50-130 Hz;
- **Video amplifier**: Bandwidth 50 Hz to 170 MHz; Pulse Rise/Fall Time <4.0 ns
- **Geometric distortion**: Raster stability is 0.05 mm for maximum swim and jitter.
- **Deflection linearity**: Non-linearity is <2%.
- **Product quality**: Unit without cathode ray tube approximately 78,000 operating hours. Cathode ray tube typically 20,000 operating hours, minimum 10,000 operating hours.
- **Physical dimensions**: Depth: 20.5 inches, Width: 19.6 inch, Height: 19 inch, Weight: 73 pounds
- **Front panel**: Image controls: Power on/off, contrast, brightness; Geometry controls: H/V-phase, H/V-amplitude, pin & barrel, image rotation.
- **Service access:** Adjustment of all parameters needed for service is by way of the serial RS232 interface using a PC (MS Windows).

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Quantum Data 903 250 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter) and Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially available stereo products:

- Nuvision 19-inch LCD shutter with passive polarized eyeglasses.
- StereoGraphics 19-inch LCD ZScreen with passive polarized eyeglasses.
- StereoGraphics active shutter glasses.

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1600 x 1200 format is 30.8 dB in a dark room. It decreases to under 22 dB (the minimum acceptable for IEC) in 13 fc diffuse ambient illumination.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

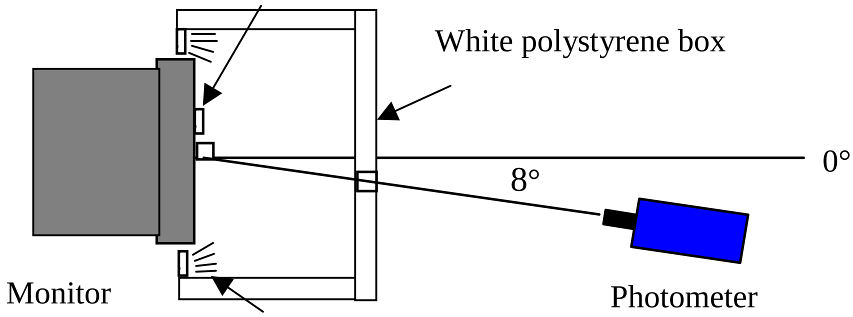
Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93}. Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a white polystyrene box. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Define dynamic range by: $DR=10\log(Lmax/Lmin)$



- Top View -

Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance (DHR) of Faceplate

VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.5 fc
Reflected Luminance	1.52 fL
Faceplate Reflectance	7.4 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. Full screen white-to-black dynamic range decreases from 30.8 dB in a dark room to 22 dB (the absolute threshold for IEC) in 13 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.1 fL.

	Displayed Addressable Format
Ambient Illumination	**1600 x 1200**
0 fc (Dark Room)	30.8 dB
1 fc	29.0 dB
2 fc	27.8 dB
3 fc	26.8 dB
4 fc	26.0 dB
5 fc	25.3 dB
6 fc	24.7 dB
7 fc	24.2 dB
8 fc	23.7 dB
9 fc	23.3 dB
10 fc	23.0 dB
11 fc	22.6 dB
12 fc	22.3 dB
13 fc	22.0 dB
14 fc	21.7 dB
15 fc	21.4 dB

II.2. Maximum Luminance (Lmax)

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.*

The highest luminance for Lmax was 174 fL measured at screen center in 1600 x 1200 format. With the front panel adjustment, it could be reduced to 35fL, or lower.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held colorimeter (Minolta CA-100).

Table II.2-1. Maximum Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	12333K	0.246	0.307	174fL
1600 x 1200				35.6 fL

II.3. Luminance (Lmax) and Color Uniformity

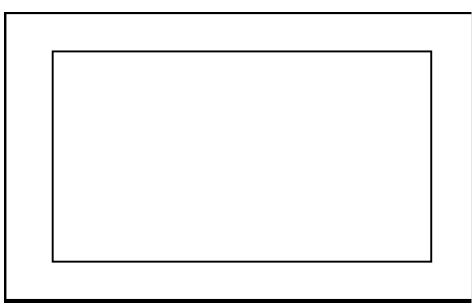
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 15.5% across the screen. Chromaticity variations were less than 0.005 delta u'v' units.

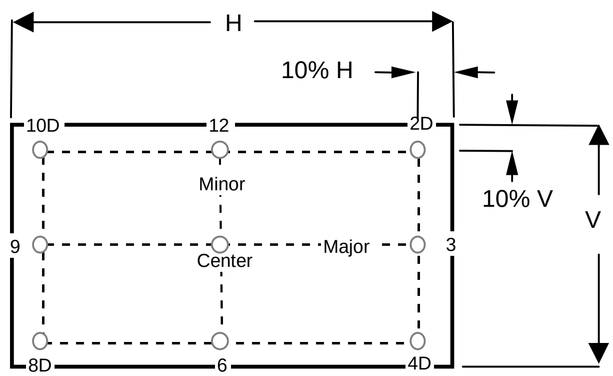
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment:
- Video generator
- Photometer
- Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1



Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of Δ u´v´.

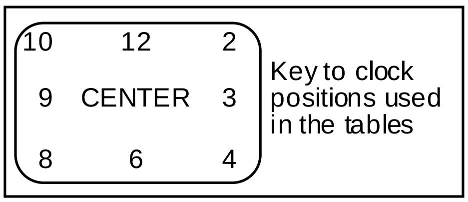
Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1.Spatial Uniformity of Luminance and Color

Color and luminance (in fL) for full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT	CIE x	CIE y	L, fL
center	12333	0.246	0.307	174.0
2	13084	0.242	0.303	147.0
3	12807	0.243	0.305	152.0
4	12889	0.243	0.304	148.0
6	12698	0.244	0.305	159.0
8	13235	0.243	0.300	147.0
9	13145	0.243	0.301	151.0
10	13260	0.242	0.301	147.0
12	12972	0.243	0.303	160.0



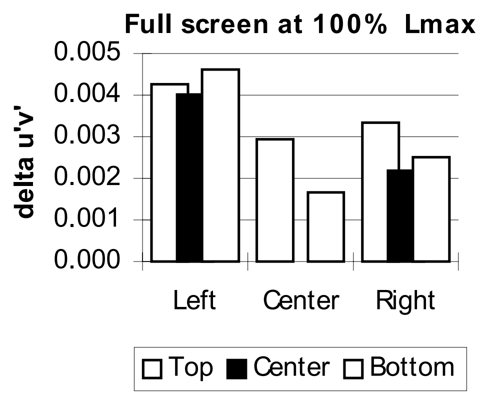


Fig.II.3-3. Spatial Uniformity of Luminance Chromaticity.
(Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 1.41 % +/- 0.12% on a small black patch surrounded by a large full white area.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:
- Photometer
- Video generator

Test Pattern:

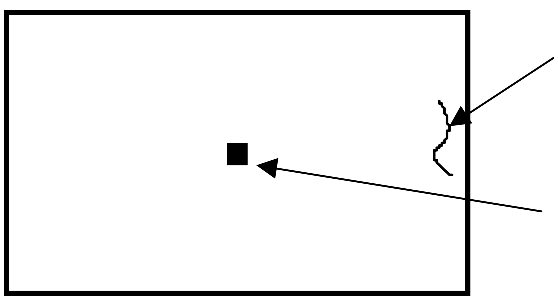


Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that

CRT beam is just on the verge of being cut off. These measurements should be made with a photometer which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\%\ \text{Halation} = L_{black} \,/\, (L_{white} - L_{black}) \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,

L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1600 x 1200 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	1.92fL ± 4%	1.84fL to 2.00fL
Lwhite	136fL ± 4%	131fL to 141fL
Halation	**1.41% ± 0.12%**	**1.30% to 1.53%**

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of the measured white point is 12333K and is not specified for monochrome monitors for IEC.

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Positive increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are n four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM model to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM model was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

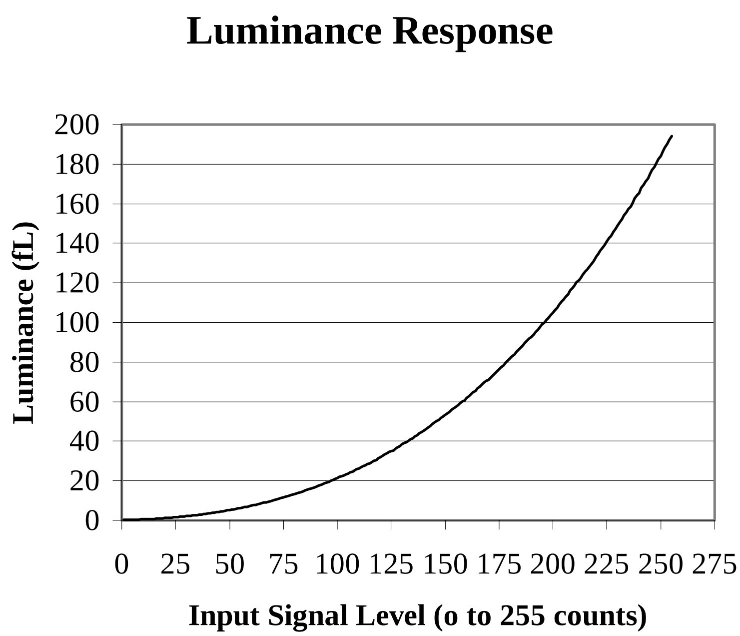


Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts. Target levels 000 to 127.

Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.189	0	0
39	1	0.215	0.026	4
39	2	0.239	0.024	4
39	3	0.27	0.031	5
40	4	0.298	0.028	4
40	5	0.33	0.032	4
41	6	0.369	0.039	5
41	7	0.407	0.038	5
41	8	0.442	0.035	3
42	9	0.487	0.045	5
42	10	0.535	0.048	5
42	11	0.582	0.047	4
43	12	0.635	0.053	5
43	13	0.686	0.051	4
43	14	0.746	0.06	5
44	15	0.804	0.058	5
44	16	0.874	0.07	5
44	17	0.939	0.065	4
45	18	1.017	0.078	5
45	19	1.079	0.062	4
45	20	1.162	0.083	5
46	21	1.247	0.085	5
46	22	1.332	0.085	4
46	23	1.42	0.088	5
47	24	1.506	0.086	4
47	25	1.597	0.091	4
48	26	1.696	0.099	5
48	27	1.795	0.099	4
48	28	1.891	0.096	4
49	29	2.012	0.121	5
49	30	2.119	0.107	4
49	31	2.24	0.121	5
50	32	2.36	0.12	4
50	33	2.482	0.122	4
50	34	2.614	0.132	5
51	35	2.746	0.132	4
51	36	2.878	0.132	4
51	37	3.012	0.134	4
52	38	3.158	0.146	4
52	39	3.307	0.149	5
52	40	3.45	0.143	3
53	41	3.613	0.163	5
53	42	3.737	0.124	3
53	43	3.914	0.177	4
54	44	4.063	0.149	4
54	45	4.214	0.151	3
55	46	4.45	0.236	6
55	47	4.623	0.173	3
55	48	4.825	0.202	5
56	49	5.017	0.192	3
56	50	5.157	0.14	3
56	51	5.423	0.266	5
57	52	5.624	0.201	4
57	53	5.811	0.187	4
57	54	6.05	0.239	4
58	55	6.187	0.137	2
58	56	6.479	0.292	5
58	57	6.681	0.202	3
59	58	6.947	0.266	4
59	59	7.168	0.221	4
59	60	7.419	0.251	4
60	61	7.636	0.217	3
60	62	7.897	0.261	3
61	64	8.412	0.252	3
61	65	8.687	0.275	4
62	66	8.951	0.264	3
62	67	9.203	0.252	4
62	68	9.497	0.294	3
63	69	9.751	0.254	3
63	70	10.02	0.269	3
63	71	10.29	0.27	3
64	72	10.62	0.33	4
64	73	10.87	0.25	3
64	74	11.19	0.32	3
65	75	11.6	0.41	4
65	76	11.92	0.32	4
65	77	12.24	0.32	3
66	78	12.64	0.4	4
66	79	12.92	0.28	2
66	80	13.21	0.29	3
67	81	13.52	0.31	3
67	82	13.87	0.35	3
67	83	14.31	0.44	4
68	84	14.64	0.33	3
68	85	15.07	0.43	3
69	86	15.46	0.39	3
69	87	15.86	0.4	3
69	88	16.17	0.31	3
70	89	16.54	0.37	3
70	90	16.98	0.44	3
70	91	17.37	0.39	3
71	92	17.84	0.47	3
71	93	18.26	0.42	3
71	94	18.66	0.4	3
72	95	19.14	0.48	3
72	96	19.51	0.37	3
72	97	19.97	0.46	2
73	98	20.32	0.35	3
73	99	20.94	0.62	4
73	100	21.34	0.4	2
74	101	21.85	0.51	3
74	102	22.3	0.45	3
74	103	22.77	0.47	2
75	104	23.27	0.5	3
75	105	23.76	0.49	3
76	106	24.26	0.5	3
76	107	24.62	0.36	2
76	108	25.2	0.58	3
77	109	25.87	0.67	3
77	110	26.35	0.48	3
77	111	26.84	0.49	2
78	112	27.44	0.6	3
78	113	27.93	0.49	2
78	114	28.44	0.51	3
79	115	28.89	0.45	2
79	116	29.6	0.71	3
79	117	30.06	0.46	2
80	118	30.56	0.5	2
80	119	31.35	0.79	4
80	120	31.96	0.61	2
81	121	32.54	0.58	3
81	122	33.21	0.67	3
81	123	33.83	0.62	2
82	124	34.5	0.67	3
82	125	35.04	0.54	2
83	126	35.3	0.26	1

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60	63	8.16	0.263	4

83	127	36.28	0.98	4

Table II.6-2. System Tonal Transfer at center screen as a function of input counts
Target levels 128 to 255.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
83	128	36.86	0.58	2	106	192	95.12	1.28	2
84	129	37.59	0.73	3	106	193	96.55	1.43	2
84	130	38.41	0.82	3	106	194	97.8	1.25	2
84	131	39.03	0.62	2	107	195	99.18	1.38	2
85	132	39.56	0.53	2	107	196	100.1	0.92	1
85	133	39.99	0.43	1	107	197	101.2	1.1	2
85	134	40.98	0.99	4	108	198	102.4	1.2	2
86	135	41.36	0.38	1	108	199	103.8	1.4	2
86	136	42.38	1.02	3	108	200	105	1.2	2
86	137	43.08	0.7	2	109	201	106.4	1.4	1
87	138	43.87	0.79	3	109	202	107.5	1.1	2
87	139	44.66	0.79	2	109	203	109.2	1.7	2
87	140	45.21	0.55	2	110	204	110.8	1.6	2
88	141	46.09	0.88	3	110	205	111.6	0.8	2
88	142	46.96	0.87	3	111	206	112.9	1.3	1
88	143	47.69	0.73	2	111	207	114.1	1.2	2
89	144	48.64	0.95	2	111	208	116.1	2	2
89	145	49.38	0.74	3	112	209	117.4	1.3	2
90	146	50.11	0.73	2	112	210	118.7	1.3	2
90	147	50.73	0.62	1	112	211	120.5	1.8	2
90	148	51.78	1.05	3	113	212	121.5	1	1
91	149	52.48	0.7	2	113	213	122.8	1.3	2
91	150	53.3	0.82	2	113	214	124.2	1.4	1
91	151	54.2	0.9	3	114	215	125.8	1.6	2
92	152	54.84	0.64	1	114	216	126.7	0.9	1
92	153	55.83	0.99	3	114	217	128.2	1.5	2
92	154	56.59	0.76	2	115	218	129.9	1.7	2
93	155	57.38	0.79	2	115	219	131.2	1.3	2
93	156	58.38	1	2	115	220	133.2	2	2
93	157	59.28	0.9	2	116	221	134.7	1.5	1
94	158	60.15	0.87	3	116	222	136.3	1.6	2
94	159	60.56	0.41	1	116	223	137.8	1.5	2
94	160	61.88	1.32	3	117	224	139.3	1.5	1
95	161	62.84	0.96	2	117	225	140.8	1.5	2
95	162	63.8	0.96	2	118	226	142.6	1.8	2
95	163	64.71	0.91	2	118	227	143.7	1.1	1
96	164	65.35	0.64	1	118	228	145.8	2.1	2
96	165	66.52	1.17	3	119	229	147.1	1.3	2
97	166	67.54	1.02	2	119	230	149	1.9	2
97	167	68.68	1.14	3	119	231	150.8	1.8	1
97	168	69.48	0.8	1	120	232	152.1	1.3	2
98	169	70.56	1.08	2	120	233	154	1.9	2
98	170	70.98	0.42	1	120	234	155.8	1.8	1
98	171	71.78	0.8	2	121	235	157.3	1.5	2
99	172	73.06	1.28	2	121	236	158.7	1.4	1
99	173	74.26	1.2	3	121	237	160.6	1.9	2
99	174	75.45	1.19	2	122	238	162.7	2.1	2
100	175	76.32	0.87	2	122	239	164.4	1.7	1
100	176	77.46	1.14	2	122	240	165.5	1.1	1
100	177	78.4	0.94	2	123	241	167.8	2.3	2
101	178	79.62	1.22	2	123	242	169.6	1.8	2
101	179	80.72	1.1	2	123	243	171.3	1.7	2
101	180	81.98	1.26	2	124	244	172.8	1.5	1
102	181	82.95	0.97	2	124	245	175	2.2	2
102	182	83.94	0.99	2	125	246	176.9	1.9	1
102	183	85.05	1.11	2	125	247	178.8	1.9	2
103	184	86.19	1.14	2	125	248	180.6	1.8	1
103	185	87.24	1.05	1	126	249	182.4	1.8	2
104	186	88.43	1.19	2	126	250	184.1	1.7	1
104	187	89.67	1.24	2	126	251	186.4	2.3	2
104	188	90.89	1.22	2	127	252	188.2	1.8	2
105	189	92.02	1.13	2	127	253	190.2	2	1
105	190	92.42	0.4	1	127	254	192.2	2	2
105	191	93.84	1.42	2	128	255	194.3	2.1	2

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

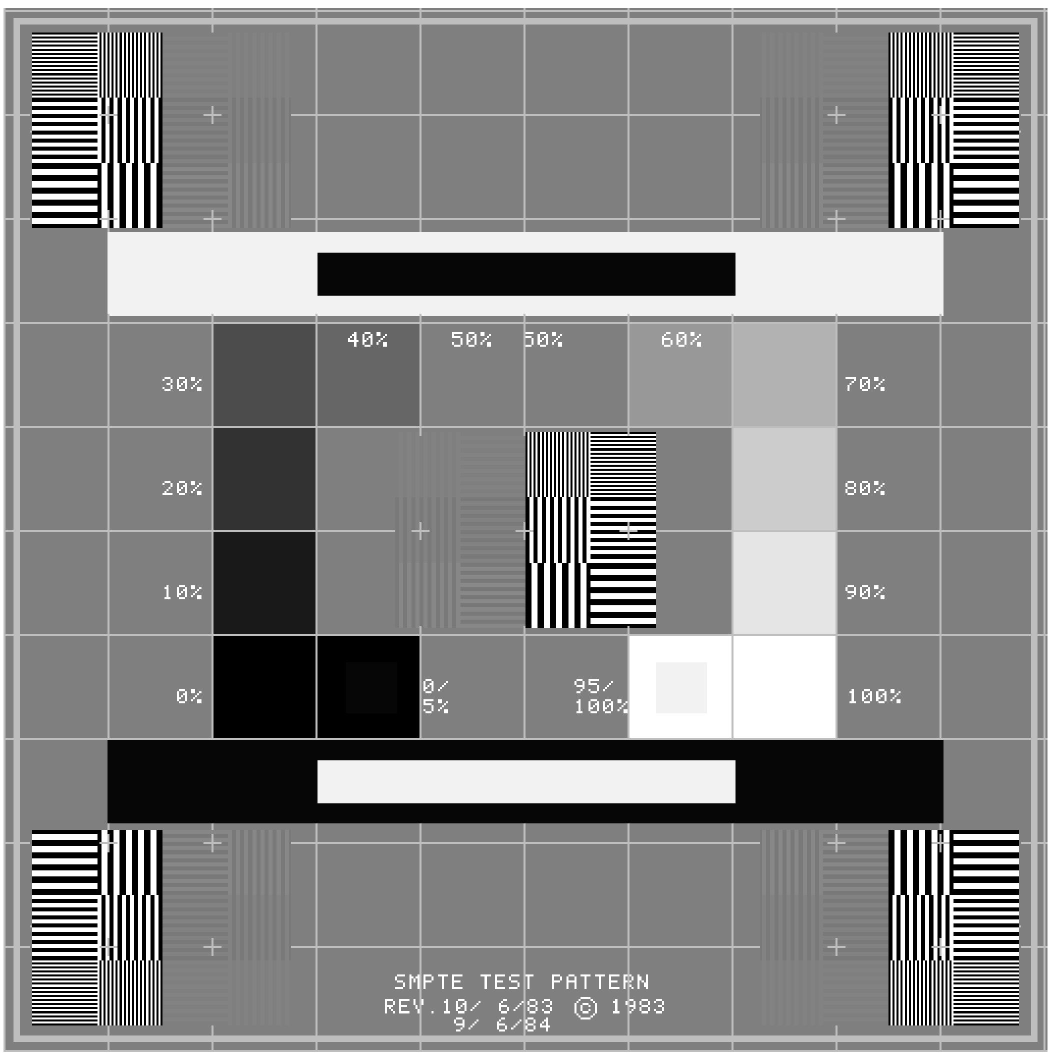


Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts was observed in the Precision Imaging Corporation 21si monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested formats (HxV): ***1600 x 1200x 72 Hz,*** *and* ***1024 x 1024 x 120 Hz.***

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode	Stereo Mode
1600 x 1200	**1024 x 1024**

II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is within 0.6%.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches)	15.533 x 11.580
H x V Pixel Spacing (mils)	9.71 x 9.65 mils
H x V Pixel Aspect Ratio	**H = V + 0.6%**

II.11. Screen Size (Viewable Active Image)

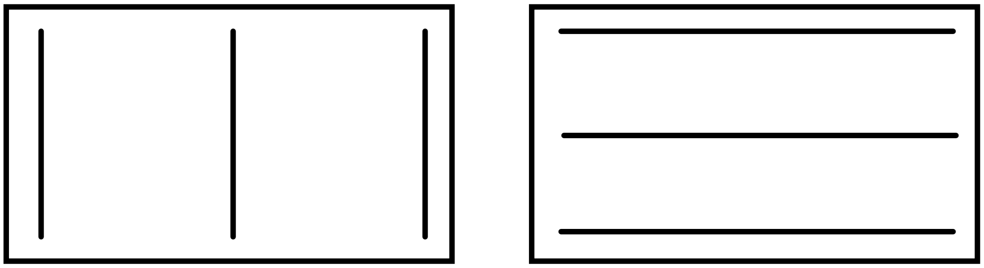
Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

Image size as tested was 19.374 inches in diagonal.

Objective: Measure beam position on the CRT display to quantify width and height of active image size visible by the user (excludes any overscanned portion of an image).

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches) Diagonal Image Size (inches)	15.533 x 11.580 **19.374**

II.12. Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax (Lmax=174 fL) exceeded Cm = 42% in Zone A, and exceeded Cm = 33% in Zone B. When Lmax was set to 35 fL, the contrast modulation for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 58% in Zone A, and exceeded Cm = 49% in Zone B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

Procedure: The maximum video modulation frequency for each 1600 x 1200 format was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax.

Zone A is defined as a 24 degree subtense circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 51% in Zone A, and is equal to or greater than 35% in Zone B.

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

Table II.12-1. Contrast Modulation
Corrected for lens flare and Zone Interpolation

Zone A 7.6-inch diameter circle for 24-degree subtense at 18-inch viewing distance

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	70%	49%			71%	61%			67%	46%
			76%	54%	74%	60%	75%	53%		
Major	70%	46%	75%	52%	79%	58%	72%	45%	65%	33%
			75%	56%	72%	60%	78%	55%		
Bottom	68%	53%			68%	62%			75%	50%

Zone A 9.57-inch d**iameter circle for 40% area**

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	70%	49%			71%	61%			67%	46%
			75%	53%	72%	60%	73%	52%		
Major	70%	46%	73%	50%	79%	58%	71%	42%	65%	33%
			74%	55%	70%	61%	77%	54%		
Bottom	68%	53%			68%	62%			75%	50%

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was set to 103 ppi for the 1600 x 1200-line addressable format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches) H x V Pixel Density, ppi	15.533 x 11.580 **103 x 104**

II.14. Moiré

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Not applicable to monochrome monitors.

II.15. Straightness

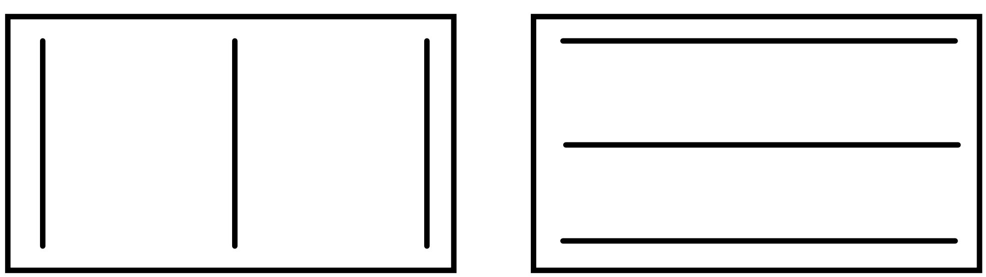
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.55% of the image width or height.

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.

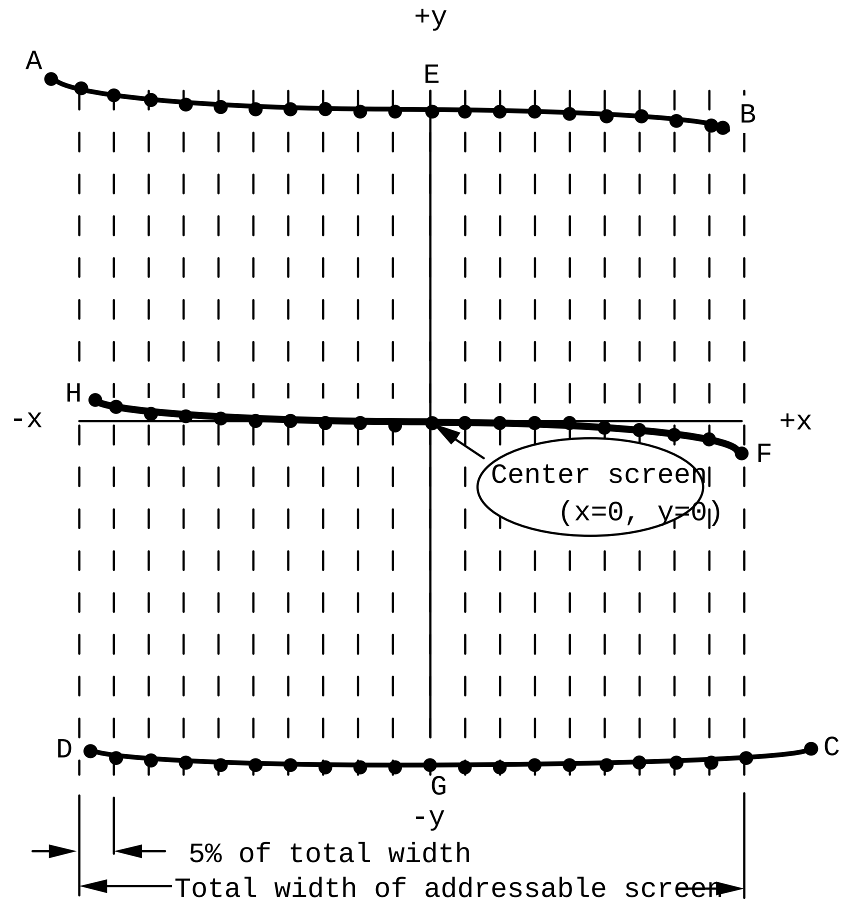


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates along the length of a nominally straight line. Measure x, y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x, y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-1. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Straightness
Tabulated x, y positions at 5% addressable screen increments along nominally straight lines.

Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-7807	5753	-7831	-5806	-7826	-39	20	5812	-7820	5743	7713	5735
-7200	5763	-7200	-5800	-7200	-32	20	5400	-7821	5400	7716	5400
-6400	5775	-6400	-5795	-6400	-27	17	4800	-7821	4800	7721	4800
-5600	5781	-5600	-5788	-5600	-20	15	4200	-7825	4200	7730	4200
-4800	5786	-4800	-5786	-4800	-13	13	3600	-7832	3600	7737	3600
-4000	5792	-4000	-5789	-4000	-5	10	3000	-7838	3000	7743	3000
-3200	5799	-3200	-5791	-3200	0	7	2400	-7843	2400	7746	2400
-2400	5807	-2400	-5797	-2400	3	5	1800	-7846	1800	7743	1800
-1600	5816	-1600	-5806	-1600	5	3	1200	-7845	1200	7739	1200
-800	5824	-800	-5813	-800	6	2	600	-7844	600	7732	600
0	5828	0	-5818	0	8	1	0	-7843	0	7726	0
800	5830	800	-5821	800	7	0	-600	-7844	-600	7721	-600
1600	5827	1600	-5821	1600	4	0	-1200	-7844	-1200	7716	-1200
2400	5821	2400	-5820	2400	1	0	-1800	-7844	-1800	7711	-1800
3200	5810	3200	-5816	3200	-2	1	-2400	-7843	-2400	7707	-2400
4000	5800	4000	-5813	4000	-6	2	-3000	-7840	-3000	7702	-3000
4800	5789	4800	-5809	4800	-11	5	-3600	-7836	-3600	7697	-3600
5600	5780	5600	-5810	5600	-17	8	-4200	-7832	-4200	7693	-4200
6400	5768	6400	-5813	6400	-22	13	-4800	-7829	-4800	7692	-4800
7200	5755	7200	-5813	7200	-25	16	-5400	-7830	-5400	7697	-5400
7711	5745	7703	-5817	7720	-35	18	-5816	-7838	-5814	7704	-5820

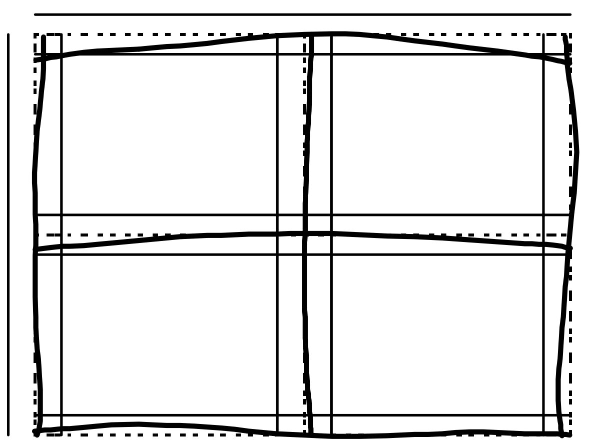


Figure II.15-3 Waviness of Precision Imaging Corporation 21si Monochrome monitor in 1600 x 1200 mode. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for the1600 x 1200 format was set to 72 Hz.
Vertical refresh rate for the 1024 x 1024 stereo format was set to 120 Hz.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Monoscopic Mode	**Stereo Mode**
Addressability	**1600 x 1200**	**1024 x 1024**
Vertical Scan	72 Hz	120 Hz
Horizontal Scan	kHz	kHz

II.17. Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio was averaged 30.7 to 1 (39.4 left, 22.0 right) at screen center. Luminance of white varied by up to 12.8% across the screen. Chromaticity variations of white were less than 0.008 delta u'v' units. The extinction ratio for the ZScreen and the active shutter glasses exceeded the IEC minimum value.

Objective: Measure stereo extinction ratio

Equipment: Two "stereo" pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially available Nuvision 19-inch LCD shutter with passive polarized eyeglasses, with a StereoGraphics ZScreen and passive glasses, or with active StereoGraphics shutter glasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

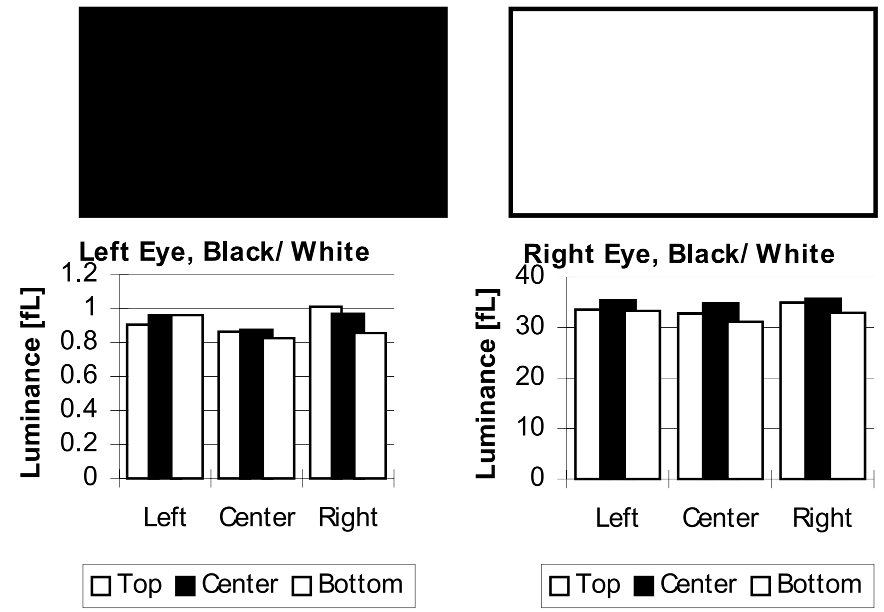


Fig.II.17-1. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

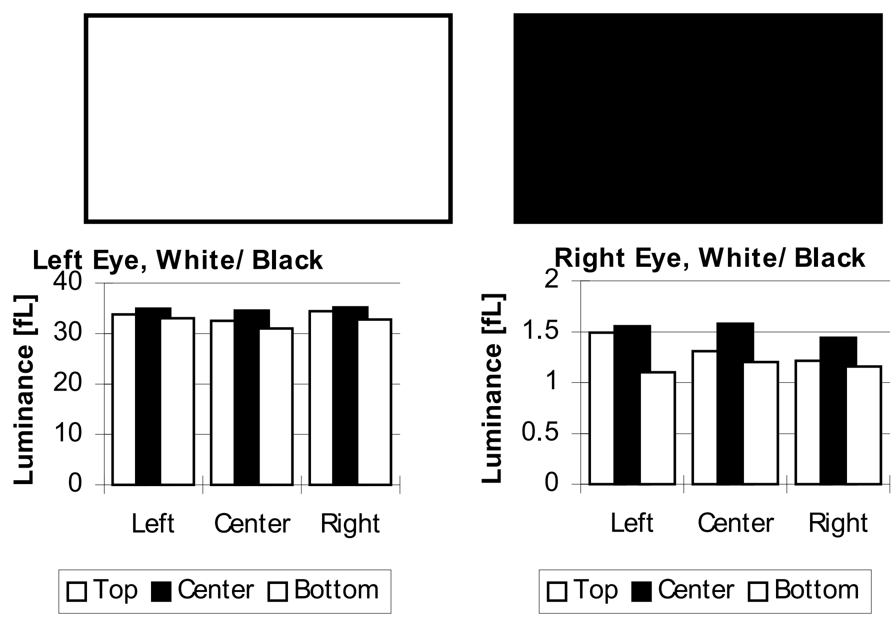


Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

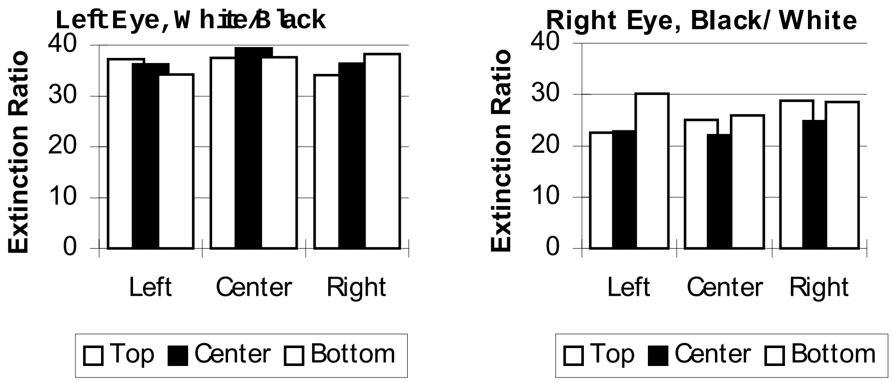


Fig.II.17-3. Spatial Uniformity of extinction ratio in stereo mode.

Fig.II.17-4 Spatial Uniformity of chromaticity of white in stereo mode.

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 0.59% of full screen.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

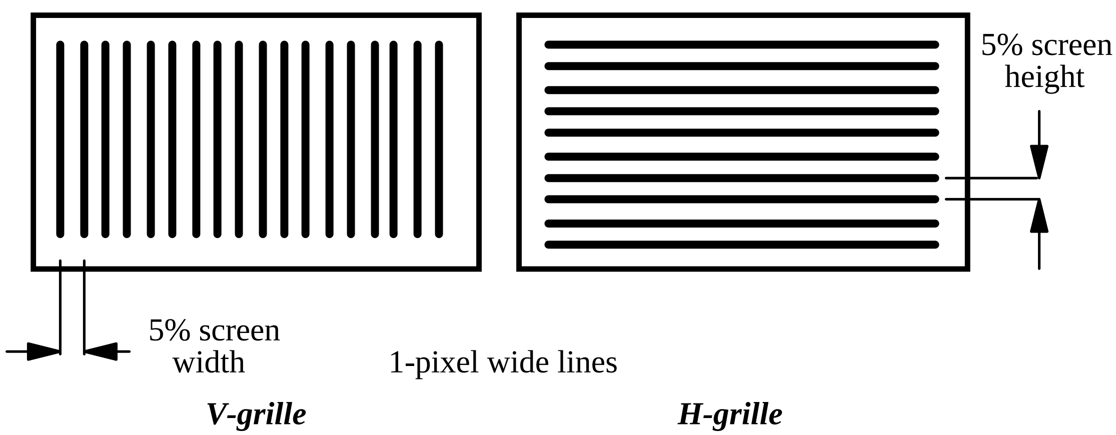


Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x, y-translation stage to measure screen x, y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

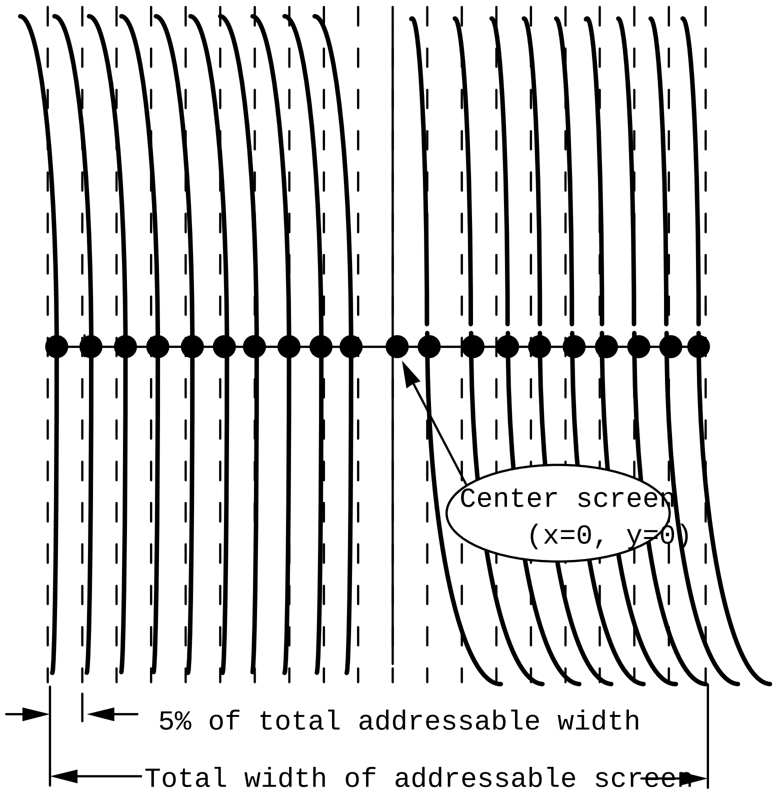


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

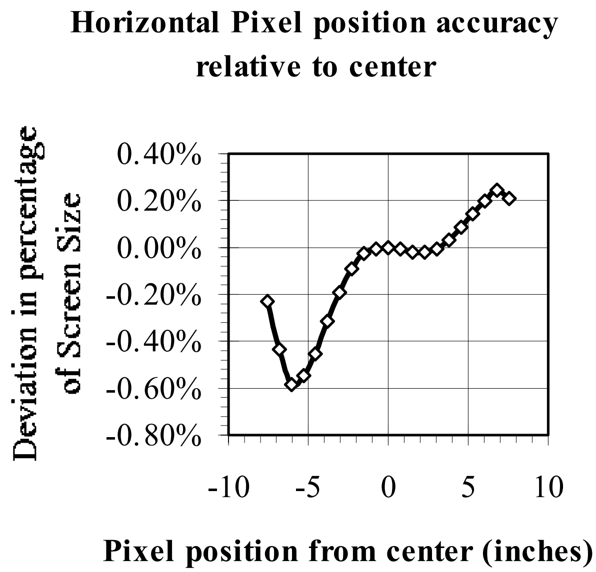
Data: Tabulate x, y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	0.59%	0.24%	0.04%	0.25%

Table II.18-2. Horizontal and Vertical Nonlinearities Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	**Right Side**	**Top**	**Bottom**
-7605	7602	5696	-5720
-6879	6850	5127	-5158
-6145	6086	4557	-4588
-5382	5321	3986	-4014
-4611	4555	3416	-3437
-3833	3790	2846	-2862
-3057	3027	2276	-2287
-2285	2268	1707	-1713
-1518	1511	1140	-1141
-758	756	570	-570
0	0	0	0



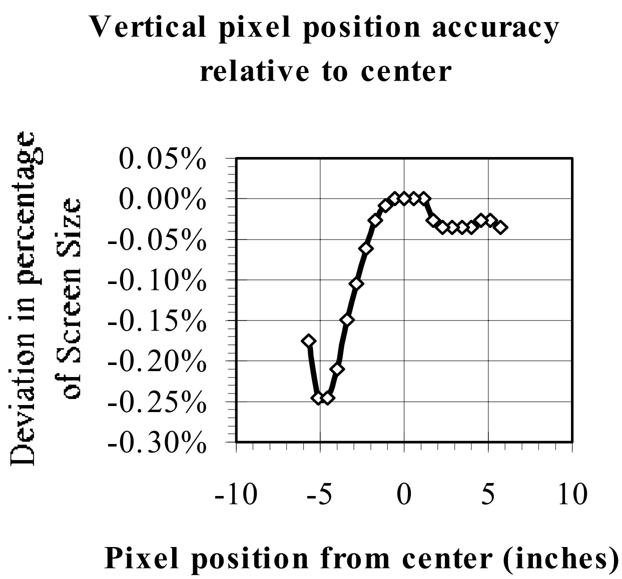


Fig. II.18-5 Horizontal and vertical linearity characteristics.

II.19. Jitter/Swim/Drift

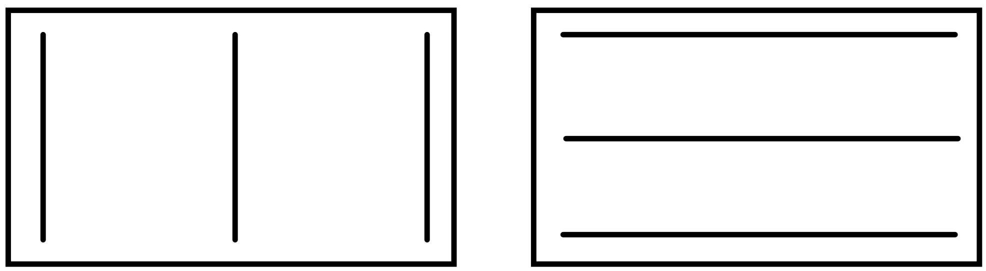
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p 80.

Maximum jitter and swim/drift were 1.79 mils and 2.14 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depend upon the amplitude and frequency of the motions which can be caused by imprecise control electronics or external magnetic fields.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift

Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.

			H-lines	V-lines	
10D corner	Max Motions				
		Jitter	1.72	1.86	
		Swim	2.01	2.11	
		Drift	2.21	2.21	
Black Tape	Max Motions				
		Jitter	0.046	0.066	
		Swim	0.051	0.071	
		Drift	0.077	0.071	
Less Tape Motion					maximums
		Jitter	1.67	1.79	1.79
		Swim	1.96	2.04	2.04
		Drift	2.13	2.14	2.14

II.20 Warmup Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 41 minute warmup was necessary for luminance stability of Lmin = 0.1 fL +/- 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1280 x 1024 format in graphical form. The luminance remains very stable after 49 minutes.

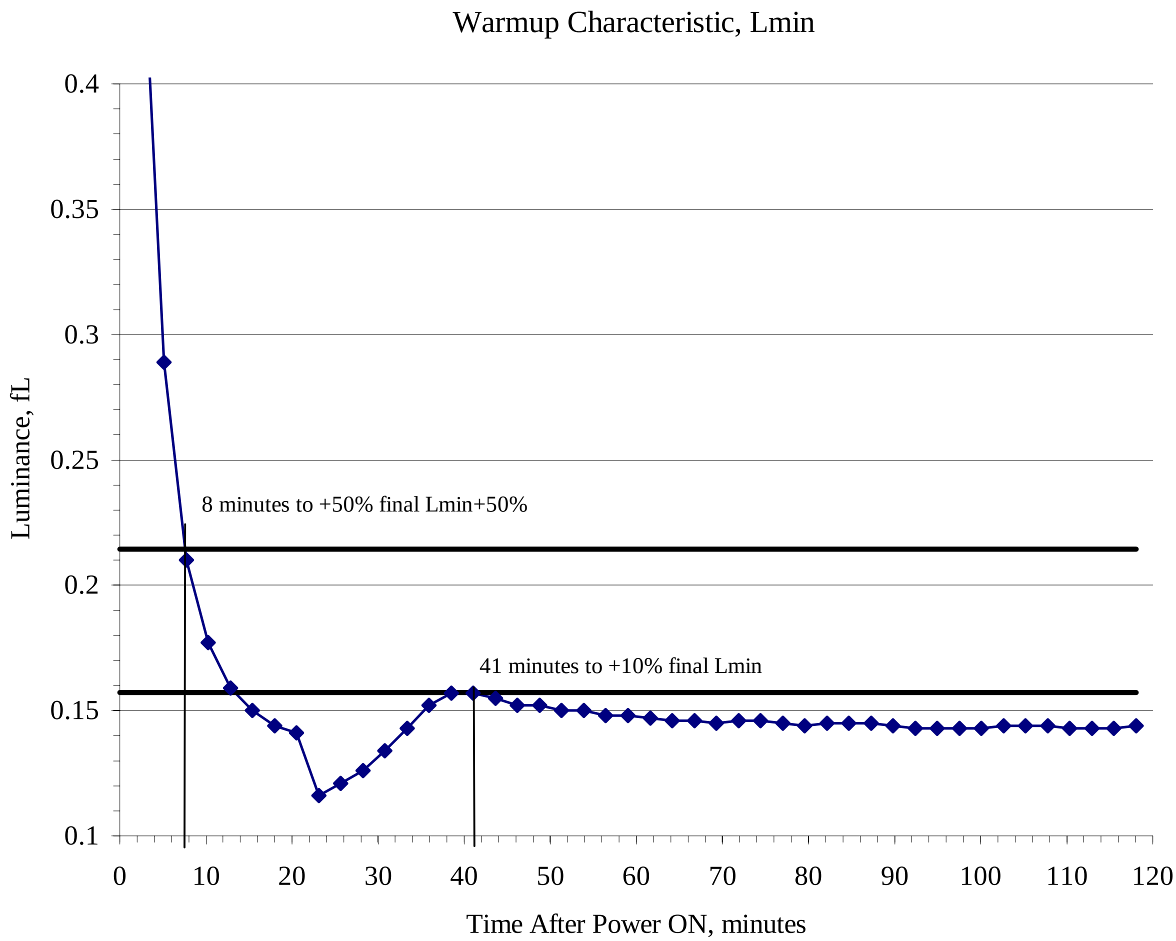


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).